Surface Water and Ocean Topography (SWOT) Project

SWOT Product Description
Long Name: Level 1B KaRIn low rate interferogram product
Short Name: L1B_LR_INTF

Revision A (DRAFT)

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CHANGE LOG

VERSION	DATE	SECTIONS CHANGED	REASON FOR CHANGE
Preliminary	2017-02-16	ALL	Preliminary version Approved for export (LRR-028890)
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1 Introduction

1.1 Purpose

The purpose of this document is to describe the Level 1B Ka-band Radar Interferometer (KaRIn) low rate (LR) interferogram science data product from the Surface Water and Ocean Topography (SWOT) mission. This data product is also referenced by the short name L1B_LR_INTF.

1.2 Document Organization

Section 2 provides a general description of the product, including its purpose, the relevant requirements, and latency.

Section 3 provides the structure of the product, including granule definition, file organization, spatial resolution, temporal and spatial organization of the content, the size and data volume.

Section 4 provides qualitative descriptions of the information provided in the product.

Section 5 provides a detailed identification of the individual fields within the L1B_LR_INTF product, including for example their units, size, coordinates, etc.

Section 6 provides the list of references.

1.3 Document Conventions

When the specific names of data variables and groups of the data product are given in the body text of this document, they are usually represented in italicized text.

2 Product Description

2.1 Purpose

The L1B_LR_INTF data product provides low-rate (LR) data from the SWOT KaRIn instrument, including interferograms, calibrated estimates of normalized radar cross section (NRCS or sigma0), and volumetric correlation, in response to the SWOT project requirements in [1]. The interferograms of the L1B_LR_INTF product are corrected for systematic angular phase biases. The power and noise measurements in the raw telemetry and calibration parameters for the KaRIn instrument are used to estimate sigma0 and volumetric correlation. Intermediate quantities used to make these calculations such as signal-to-noise ratio (SNR), angular correlation, and radiometric calibration terms are provided as a resource to allow users to gain further insight into the measurements and to perform specialized processing of the data. Geometry information, including co-registered spacecraft attitude and ephemeris data, is included for the same reason.

SWOT LR data products are provided continuously in time and globally in space, but they may not be useful over land surfaces.

A general description of the algorithms that are used to generate this data product can be found in [2]. The primary components of this data product are listed below.

1. Interferogram, corrected for angular phase biases
2. Interferogram reference location
3. Phase bias correction that was applied to the interferogram
4. Normalized radar cross section (sigma0)
5. Volumetric correlation
6. Uncertainty estimates for measured quantities
7. Correction terms, quality flags, and associated information
8. Spacecraft ephemeris and attitude information

The L1B_LR_INTF data product also contains so-called “mitigation product” data from the KaRIn instrument. The mitigation data are not used in nominal science processing and are included only to provide extra information if needed. Details on these data fields are TBD.

2.2 Latency

The L1B_LR_INTF product is generated with a latency of at most 45 days from data collection. Versions of the L1B_LR_INTF product may be produced based on either Medium-accuracy Orbit Ephemeris (MOE) or Precise Orbit Ephemeris (POE) [3] information of the spacecraft position and velocity, with the former enabling considerably shorter latencies.

3 Structure

3.1 Granule Definition

The L1B_LR_INTF data product is given in half-orbit (pass) granules with full-swath (both left and right half swaths) cross-track coverage. The granule boundaries are near the northernmost and southernmost points in the orbit. One granule spans an along-track distance of approximately 20,000 km. The cross-track extent of each half swath depends on the on-board configuration of the KaRIn instrument, but typically, each half swath spans 5–65 km from nadir for each of the left and right half swaths. The left and right half swaths are defined as if standing on the Earth surface facing the direction of the spacecraft velocity vector. A granule typically contains approximately 80,000 samples along track and 240 samples per half swath in cross track at the spatial posting described in Section 3.4.

Successive granules of L1B_LR_INTF data overlap by approximately ±15 km in the along-track direction in order to facilitate the generation of downstream data products. The resulting overlap is much less than 1% of the overall granule length. Further details of the granule definition of this product and related products can be found in **[4]**.

3.2 File Organization

The L1B_LR_INTF science data product adopts the NetCDF-4 file format. The product is provided as one single NetCDF file that has a section of global attributes and four groups of data: *left*, *right, tvp_left* and *tvp_right*.

Table 1. Description of file comprising the L1B_LR_INTF product.

File	Name	Description
1	Level 1B KaRIn low-rate interferogram data product.	Provides Level 1B interferogram and associated information for the left and right half swaths, as well as spacecraft ephemeris information, in separate groups.

The *left* and *right* groups have the same structure as each other and contain the KaRIn measurements for the left and right half swaths, respectively. Here, “left” and “right” are defined as if standing on the ground at the spacecraft nadir point and facing the spacecraft velocity vector.

The *tvp_left* and *tvp_right* groups contain 1-D arrays of platform and radar parameters that vary with time (or equivalently with the along-track position of the spacecraft) rather than with location on the Earth surface. These arrays are collectively known as the time varying parameter (TVP) data for each side.

A summary of the four groups of the L1B_LR_INTF product is provided in Table 2.

Table 2. Description of NetCDF Groups in the L1B_LR_INTF product

File	Group Name	Description
L1B_LR_INTF	*left*	Spatially organized KaRIn measurement data including the interferogram observed for the half swath on the left side of the nadir track for each KaRIn Doppler beam.

	right	Spatially organized KaRIn measurement data including the interferogram observed for the half swath on the right side of the nadir track for each KaRIn Doppler beam.
	tvp_left	Time varying parameters such as spacecraft position, velocity, and attitude, which vary with time rather than with location on the Earth surface, for the half swath on the left side of the nadir track.
	tvp_right	Time varying parameters such as spacecraft position, velocity, and attitude, which vary with time rather than with location on the Earth surface, for the half swath on the right side of the nadir track.

Because there is no native type for a complex floating-point value in NetCDF-4, 3-D arrays of complex values are represented in the product as 4-D arrays, where the last dimension has a depth of 2 for the real and imaginary parts (the real part is given first) of each complex value. That is, because the real and imaginary parts of array *arr* at indices *k*, *m*, and *n* cannot be represented as *arr*[*k*][*m*][*n*].*real* and *arr*[*k*][*m*][*n*].*imag*, the real and imaginary parts are represented as *arr*[*k*][*m*][*n*][0] and *arr*[*k*][*m*][*n*][1], respectively.

3.3 File Naming Convention

The L1B_LR_INTF product adopts the following naming convention:

SWOT_L1B_LR_INTF_<CycleID>_<PassID>_<RangeBeginningDateTime>_<RangeEndingDateTime>_<CRID>_<ProductCounter>.nc

3.4 Spatial Sampling and Resolution

In this document, the term "posting" refers to the spatial sampling of a horizontally gridded data set. The term "resolution" refers to the half power width of the spatial response of each measurement. The term "sampling" is used generically to refer to the manner or locations at which the data are discretized. One individual data value is called a sample. Samples from a 2-D spatial array are sometimes also called "pixels."

Following historical terminology in the synthetic aperture radar (SAR) community, rows of image samples with a common along-track or time index are called "lines" of pixels. The along-track and cross-track dimensions of a 2-D array can therefore be characterized by the number of lines and the number of pixels per line, respectively. These are specified in the product by the *num_lines* and *num_pixels* dimensions as described in Table 12 and illustrated in Figure 1. Correspondingly, the term "pixel" is sometimes used in SWOT documents to indicate the cross-track sample index within a line. The usage of the term "pixel" should be evident from context.

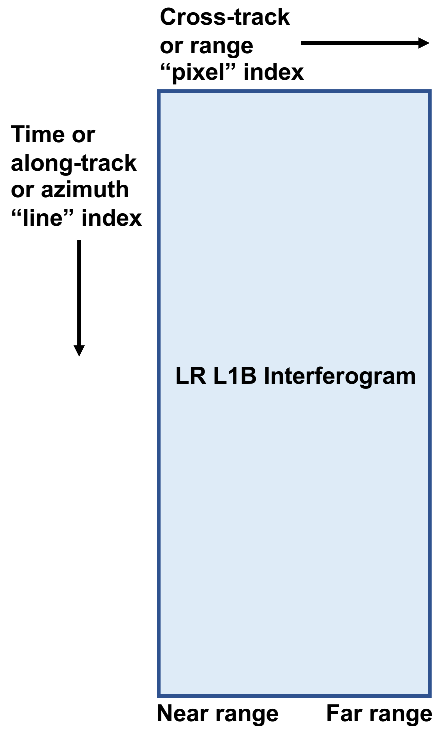

Figure 1. L1B LR interferogram image dimensions

Spatial samples of KaRIn measurements (in the *left* and *right* groups) in the L1B_LR_INTF data product are located at the native sampling of the KaRIn instrument. This sampling is largely determined by the KaRIn on-board processor (OBP). For each Doppler beam formed by the OBP [5], the sample locations in the L1B_LR_INTF product are the intersections of the beam vectors (see Section 4.1.2.1) with a reference surface used during processing. This results in a spatial posting of approximately 250 m in both the cross-track and along-track directions. Each beam has its own sampling grid. The width of the filters in the onboard processing used to produce these pixels is approximately 1 km by 1 km with approximate half-power widths (resolution) of 500 m by 500 m. Note that ground processing to create the L1B_LR_INTF product does not alter the resolution of the OBP output. In addition to the two horizontal spatial dimensions, most of the variables in the *left* and *right* groups have a third dimension (beams), which corresponds to the 9 different Doppler beams that are formed from OBP synthetic-aperture processing of cotemporaneous data. The data acquired from each beam is a contiguous, slightly irregular 2-D image. Data from different beams with the same along-track index is cotemporaneous, but not spatially aligned.

The beams are numbered 1–9. The beam pointing directions from the spacecraft are offset in angle, so the beam intersections with the Earth surface are offset in space (primarily in the along-track direction). Nominally, Beam 5 is the beam most closely aligned with the peak of the antenna gain in the azimuth direction. The spatial samples from Beams 1 and 9 are approximately 600-m removed, in opposite directions, in the along-track direction from the corresponding sample from Beam 5. Beam 1 is the aftmost beam, and samples of successively numbered beams are located further forward along the direction of spacecraft motion. This is true for both the left and right half swaths, independent of the yaw state of the spacecraft.

Figure 2 illustrates the 2-D interferograms for each beam, showing only Beams 1, 5 and 9 for simplicity. The offsets of the 2-D interferograms for each beam in the cross-track direction are exaggerated for visual clarity (the illustration is not to scale). Samples from different beams that were acquired at the same time are offset spatially; equivalently, different beams pass over the same point on the Earth surface at different times.

Figure 3 illustrates at the pixel level the sample locations from different beams for a given time instance relative to the resolution of each sample. The red numbers denote beam numbers; the locations of the numbers in the figure indicate the center of the sample for that beam. The blue square illustrates the resolution of the sample for Beam 5.

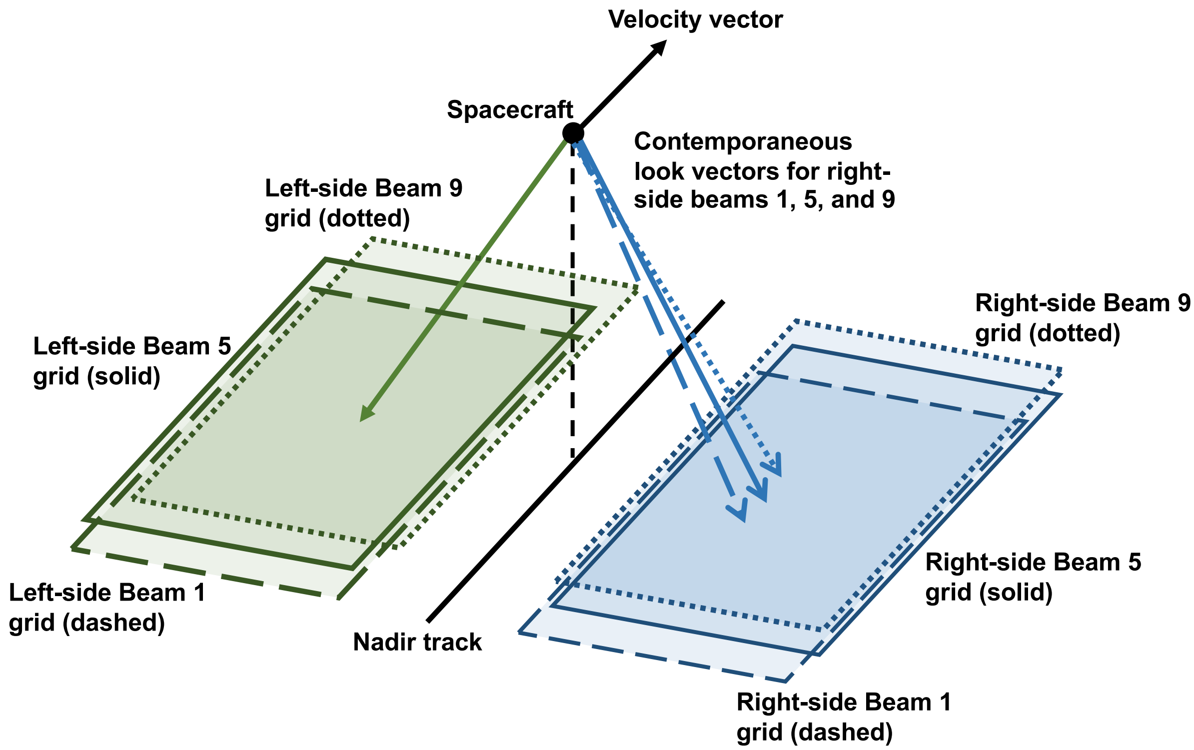

Figure 2. Illustration of the interferogram image geometry for each beam and each side.

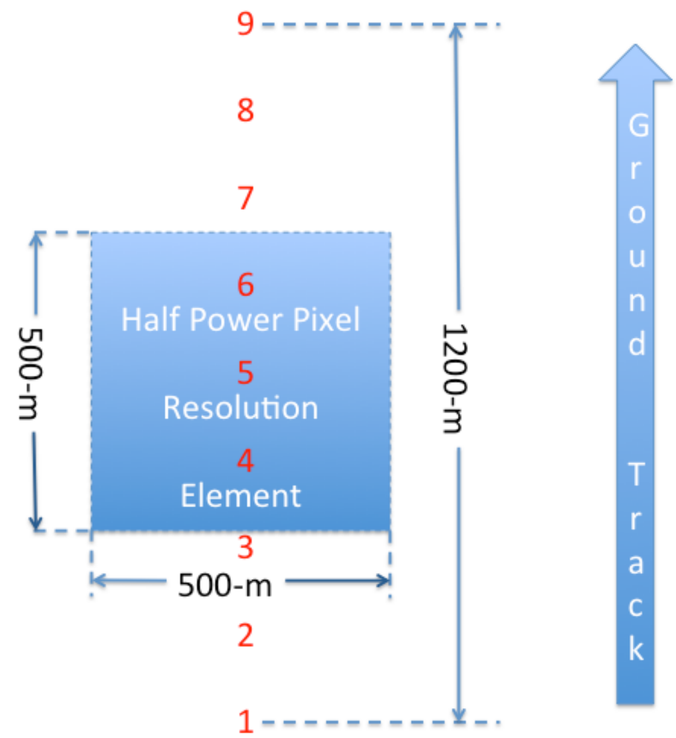

Figure 3 Spatial arrangement of beams.

The spatial resolution of all L1B_LR_INTF KaRIn measurements except for the mitigation-product variables is approximately 500 m in both the along-track and cross-track dimensions. The power mitigation product has a spatial resolution of approximately 250 m. KaRIn interferogram samples at 250 m posting and 500 m resolution are hence oversampled by a factor of approximately two; there is significant statistical correlation between neighboring samples.

The TVP data arrays (in the *tvp_left* and *tvp_right* groups) of the L1B_LR_INTF product are sampled to give a one-to-one correspondence with the along-track indices of the KaRIn spatial measurements (in the *left* and *right* groups). The TVP data arrays do not have a cross-track dimension.

3.5 Temporal Organization

A single time tag in the *tvp_left* or the *tvp_right* group is associated with each along-track line of the data product. Lines are sequential in time as the satellite moves along its ground track. Each time tag corresponds to the average time of all KaRIn radar echoes contributing to the pixels in that line. KaRIn pulses to the left and right half swaths are interleaved. The time separation between successive lines of the 250 m pixels is approximately 40 ms (assuming that the spacecraft nadir point moves at 6.5 km/s).

3.6 Spatial Organization

The half-orbit files contain KaRIn measurements from two half swaths (in the *left* and *right* groups) for each of the 9 beams. Except for five variables described below, all of the variables in each of the *left* and *right* groups have three array dimensions (*num_beams*, *num_lines*, *num_pixels*). Each of the nine beams encapsulate contiguous half-orbit images of each parameter corresponding to different sets of KaRIn radar pulses. The central (fifth) of the nine beams generally has the highest signal-to-noise ratio (SNR) and the highest quality. The 2-D images for each beam are stored with azimuth lines in time order and with range increasing with cross-track pixel index over each line. For example, *left/sig0* is the sigma0 parameter in the *left* half-swath group. Its dimensions are in the following order: *num_beams*, *num_lines*, *num_pixels*, with *num_pixels* being the fastest varying index. Indexing from 1, the scalar value *left/sig0*(1,1,1) is the sigma0 value for Beam 1 at the earliest time index (line) in the file and at the closest cross-track pixel (5 km) from nadir on the left side of the nadir track.

The five variables in each of the *left* and *right* groups that are not three dimensional are:

- The reference location has four dimensions, where the fourth dimension gives the three coordinates (x, y, z) of the position sample
- The interferogram has four dimensions, where the fourth dimension gives the real and imaginary parts of the complex interferogram values
- The mitigation power has two dimensions because it is only reported for the central beam
- The Doppler centroid used in the onboard processor has two dimensions. It varies by azimuth line and cross-track pixel but not by beam.
- The reference surface height above the ellipsoid used in the onboard processor has one dimension. It only varies by line.

3.7 Volume

Table 3 provides the expected volumes of the L1B_LR_INTF product and its relevant parts. These estimates assume that no NetCDF compression has been applied. All volume estimates assume a half-orbit, full-swath granule.

The expected volume is 41.4 GB for each individual granule of the L1B_LR_INTF product, for a total of about 1159 GB per day.

Table 3: Description of data volume of L1B_LR_INTF product

Part	Group	Name	Volume/granule
1	*left*	KaRIn measurements from left half swath	22.0 GB
2	*right*	KaRIn measurements from right half swath	22.0 GB
3	*tvp_left*	Time varying parameters for the left half swath	17 MB
4	*tvp_right*	Time varying parameters for the right half swath	17 MB
		Total	**44.1 GB**

4 Qualitative Description

4.1 Level 1B KaRIn LR INTF Data File

Several variables in the L1B_LR_INTF product are defined relative to a reference frame that is fixed to the KaRIn instrument called the KaRIn Metering Structure Frame (KMSF), illustrated in Figure 4. This frame is defined with the origin near the middle of the interferometric baseline, with the two antennas along the $+y$ and $-y$ axes. The $+z$ axis of this frame is controlled to point approximately toward nadir, so the x axis is approximately parallel or antiparallel to the Earth-relative spacecraft velocity vector. However, the spacecraft periodically performs 180˚ yaw flips (for thermal management reasons, several times per year) such that sometimes the $+x$ axis is in the direction of the velocity vector (i.e., satellite flying forward), and sometimes the $-x$ axis is in the direction of the velocity vector (i.e., satellite flying backward). Which of the $+y$ and $-y$ antennas is to the left or right of the spacecraft along-track direction therefore depends on the yaw state of the spacecraft. As elsewhere in this document, “left” and “right” are defined as if standing on the Earth surface and facing the direction of the spacecraft velocity vector.

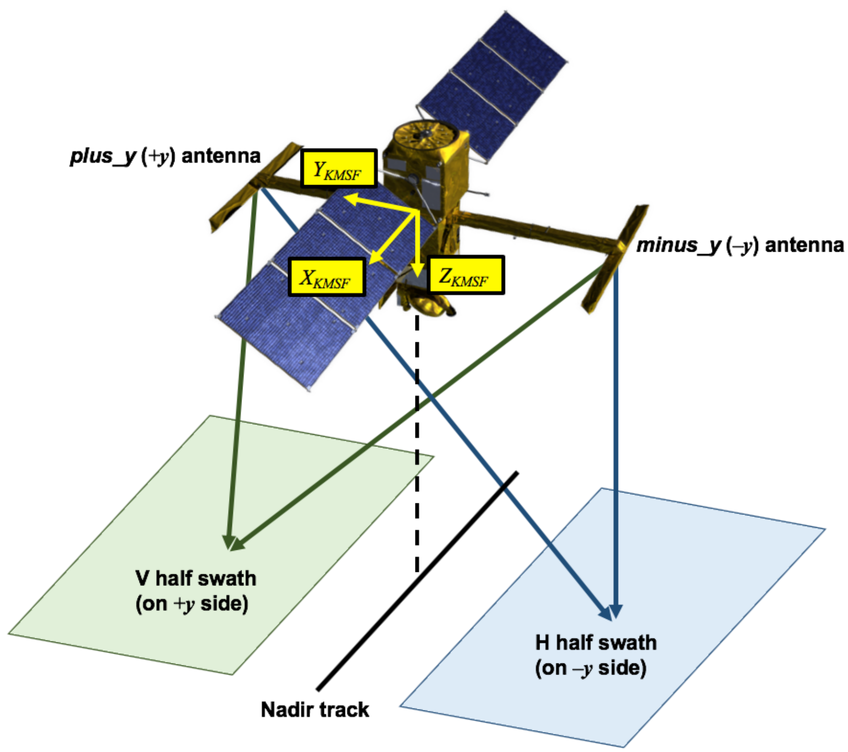

Figure 4. Illustration of the KMSF frame and the polarizations (V and H) of the two KaRIn half swaths. The velocity direction can be along $+X_{KMSF}$ or $-X_{KMSF}$ depending on the yaw state of the spacecraft.

In the L1B_LR_INTF product, variables in the TVP groups (see below) that are associated with antenna channels are defined with respect to the physical antenna and receiver hardware of the channel regardless of which side (left or right) of the nadir track the hardware was on given the yaw state of the spacecraft. Following KaRIn instrument conventions, these variables are named with the identifiers “plus_y” and “minus_y” in reference to the antennas on the $+y$ and $-y$ sides of the KaRIn frame. When the spacecraft yaw (from the *yaw* variables in the *tvp_left* and *tvp_right* groups) is close to 0˚, the +*y* and –*y* antennas are to the right and left, respectively, of the nadir track when facing in the direction of the velocity vector; the opposite is true when the yaw is close to 180˚, which indicates a yaw-flipped state.

As noted above, the interferometric data for the left and right half-swaths on the ground are given in separate product groups in the NetCDF file; the mapping of how the +y and –*y* antennas are used for each of the left and right half swaths is handled internally in the processing.

The radar signal is horizontally (H) and vertically (V) polarized for the half swaths on the -*y* and +*y* sides of the KaRIn frame, respectively. Therefore, the polarizations for the left and right half-swaths are H and V, respectively, when the yaw is close to 0˚.

When the KaRIn prime high-power amplifier (HPA) is used, the +*y* antenna transmits regardless of the yaw state. The –*y* antenna transmits when the cold-spare HPA is used (likely only in the event of a failure of the prime unit). Which of the antennas is transmitting is given by the global attribute *transmit_antenna*.

All variables that give position, velocity, and attitude relative to the Earth frame are defined with respect to the international terrestrial reference frame (ITRF). In this Earth-centered, Earth-fixed (ECEF) frame, the +*z* axis of the ECEF frame goes through the north pole, and the +*x* axis goes through both the equator (zero latitude) and the prime meridian (zero longitude).

All variables that are defined with respect to a reference ellipsoid assume the reference ellipsoid parameters that are given in the global attributes (*ellipsoid_semi_major_axis* and *ellipsoid_flattening*) of the product file itself.

4.1.1 Global Attributes

A complete list of global attributes is given in Table 7. In addition to common global attributes, several global attributes give information that describe the mode of the KaRIn radar and some relevant operating parameters:

- *wavelength*: Wavelength corresponding to the effective radar carrier frequency that should be used for height reconstruction after accounting for spectral shifts and filtering.
- *transmit_antenna*: Flag that indicates which physical KaRIn antenna (plus_y or minus_y) is transmitting.
- *antenna_to_kmsf_roll_hpol*, *antenna_to_kmsf_pitch_hpol*, *antenna_to_kmsf_yaw_hpol, antenna_to_kmsf_roll_vpol*, *antenna_to_kmsf_pitch_vpol*, *antenna_to_kmsf_yaw_vpol*: Angles defining rotation biases between the spacecraft body-fixed KaRIn Metering Structure Frame (KMSF) and the antenna frames for the H and V polarized swaths. The antenna frame for each half swath defines the common boresight direction for the pair of antennas illuminating the half swath. The sign conventions of these angles is TBD. The rotations are quasi-static calibration parameters that define how look vectors map into the elevation and azimuth angles over which knowledge of the antenna patterns is defined.

4.1.2 Left and Right Group Variables.

The *left* and *right* groups contain spatial information from the left-hand and right-hand half swaths, respectively. The variables in the two groups are identical, so the description in this section applies to both.

4.1.2.1 Reference Location

The reference location for each spatial sample and for each beam is the 3-D position of the intersection of the beam vector from the spacecraft (for the range and azimuth values corresponding to the sample spatial indices) with the reference surface used for phase bias correction. In this context, the beam vector is defined such that it represents the weighted average response to the surface given the antenna pattern and the point-target response. The reference location is not the geolocation from the KaRIn measurement; rather, the height of the reference location is defined by the reference surface. The phase of the KaRIn interferogram sample in the L1B_LR_INTF product is referred to this location. The geolocated height, which would be computed from this product, would be on the reference surface only if the interferometric phase (after all calibrations and corrections) were zero. The reference location is expressed in ECEF coordinates. In addition to the three array dimensions (*num_beams*, *num_lines*, and *num_pixels*) described above in Section 3.6, this variable has a fourth dimension of length 3, which corresponds to the *x*, *y*, and *z* components (expressed in that order) of the ECEF coordinates.

- *reference_location*: Reference location in ECEF coordinates of the sample.

The latitude and longitude of the reference location are additionally given for convenience, although these values may be of lower precision than and do not capture the full 3-D information of the *reference_location* variable (note that the reference location is generally at a non-zero height above or below the ellipsoid).

- *reference_latitude, reference_longitude*: Reference location horizontal coordinates expressed as latitude (north of the equator) and longitude (east of the prime meridian). The parameters of the reference ellipsoid are given in the global attributes of the product.

4.1.2.2 Primary Measurement: Interferogram

The complex interferogram for each half swath is stored in the variable *interferogram*. The phase of this interferogram can be used to compute the sea surface height (SSH). In addition to the three array dimensions (*num_beams*, *num_lines*, and *num_pixels*) described above in Section 3.6, this variable has a fourth dimension of length 2, which corresponds to the real and imaginary parts of the interferogram. The real part is given first. The phase of the interferogram over the interval from -pi to +pi can be obtained from a four-quadrant arctangent operation [typically, atan2(imag_part, real_part)]. The magnitude of the interferogram represents the measured (total) correlation or coherence between the echo received by the two antennas. This value is used to compute volumetric correlation after accounting for several other decorrelation terms.

The uncertainty of the phase of the interferogram as an expected 1-sigma uncertainty of the interferogram phase due to random noise is also provided as a separate variable *phase_uncert*. This value is computed analytically from the observed interferometric correlation and the effective number of looks. Note that *phase_uncert* is given in radians, not degrees. Approximately 68% of the probability distribution of the error should be within ±*phase_uncert* of zero.

- *interferogram*: Complex interferogram values, with real and imaginary parts stored in the fastest-varying array dimension. The real part is given first.
- *phase_uncert*: Estimated 1-sigma uncertainty of the interferogram phase (in radians).

4.1.2.3 Secondary Measurements: Normalized Radar Cross Section and Volumetric Correlation

In addition to the primary interferogram measurement, a co-registered map of NRCS or sigma0 is given in the product as the *sig0* variable. This value is computed from the measured power. The value is reported in linear units (not decibels); the value may be negative due to noise subtraction during estimation.

A co-registered map of volumetric correlation is given in the product as the *volumetric_correlation* variable. This value is computed from the measured interferometric correlation (magnitude of the interferogram) after adjustments for other sources of decorrelation. The volumetric correlation may be greater than 1 due to noise in the estimates used to correct for other sources of decorrelation. The volumetric correlation can be used to estimate the significant wave height.

Estimated 1-sigma uncertainties of these quantities are also reported as *sig0_uncert* and *volumetric_correlation_uncert*. The estimated 1-sigma uncertainty of sigma0 is computed analytically from the estimated signal-to-noise ratio (SNR) and effective number of looks. The estimated 1-sigma uncertainty of the volumetric correlation (*volumetric_correlation*) is also analytically computed from the estimated decorrelation terms, the estimated total correlation, and the effective number of looks.

- *sig0*: NRCS or sigma0 value estimated from the radar power measurement as a linear quantity (not decibels). The reported value is produced by taking the arithmetic mean of the sigma0 estimates from the $+y$ and $-y$ channels, and then applying a correction for atmospheric attenuation (*sig0_cor_atmos_model*). The computation of the sigma0 estimate from each channel is described below in 4.1.2.4.
- *sig0_uncert*: Estimated 1-sigma uncertainty of the NRCS or sigma0 estimate as a linear quantity.
- *volumetric_correlation*: Volumetric correlation estimate based on the observed interferometric correlation (coherence) after adjusting for other sources of decorrelation.
- *volumetric_correlation_uncert*: Estimated 1-sigma uncertainty of the volumetric correlation estimate.

4.1.2.4 Intermediate and Correction Values

Several intermediate quantities that were used to compute the primary and secondary measurements and their 1-sigma uncertainties are included in the product.

- *angular_correlation, geometric_correlation,* and *noise_correlation*: Decorrelation sources that must be removed from the total correlation estimate to obtain the volumetric correlation. The angular correlation term captures the decorrelation due to interferometric phase variations in azimuth. The geometric correlation term captures decorrelation due to the finite cross-track baseline and slant-range resolution of the instrument. The noise correlation term captures decorrelation due to the random noise of each antenna channel. Each term would ideally be 1 if there were no decorrelation. Values less than 1 are typical, but values greater than 1 are possible due to errors in the estimation.

- *x_factor_plus_y, x_factor_minus_y*: Ratio between (noise-subtracted) received power and sigma0 [sigma0 = (uncalibrated_power-noise_power)/x_factor] for the +*y* and -*y* channels. This value is given as a linear power ratio, not a decibel value. The X factor comes from the radar equation. It does not include atmospheric attenuation. It does include instrument geometry, wavelength, antenna gain, and conversion from data numbers to SI units.
- *uncalibrated_power_plus_y, uncalibrated_power_minus_y*: Received power value in downlinked telemetry before noise subtraction for the +*y* and -*y* channels. The value is in arbitrary linear units proportional to watts (not in decibels) that can be related to NRCS through the X factor.
- *noise_power_plus_y, noise_power_minus_y*: Power due to thermal noise for the +*y* and -*y* channels. The value is in the same linear units (not in decibels) as *uncalibrated_power_plus_y* and *uncalibrated_power_minus_y*. The values are estimated from KaRIn on-board calibration data. The NRCS or sigma0 estimate for each channel is (uncalibrated_power-noise_power)/x_factor.
- *model_dry_tropo _cor*, *model_wet_tropo _cor*, *iono_cor_gim_ka*: Equivalent vertical corrections due to propagation delay from the wet troposphere, the dry troposphere, and the ionosphere. The bias-corrected interferogram values are computed after adding corrections for these propagation delays to the uncorrected range along slant-range paths. The corrections account for the differential delay between the two KaRIn antennas. These corrections are reported in the product as equivalent vertical path corrections (rather than slant-path corrections) that are computed by applying obliquity factors to the slant-path correction values so that the values in the products can be directly applied to SSH quantities derived from the L1B_LR_INTF product if desired. The additional path delay relative to free space results in a negative correction value that is added as a correction to the uncorrected range. However, a decrease in the measured range gives an increase in the measured height. As such, adding the reported correction terms to the corrected SSH results in the uncorrected SSH. The corrections are based on SWOT-independent information from the European Centre for Medium-Range Weather Forecasts (ECMWF) and JPL Global Ionosphere Maps (GIM).
- *sig0_cor_atmos_model*: Correction to sigma0 due to attenuation from the atmosphere. This value is computed from weather models and reported as a linear ratio greater than 1 (not a decibel value). For example a value of 1.2 indicates that the measured sigma0 (as a linear quantity) needs to be multiplied by 1.2 to obtain the value that would have been measured without attenuation from the atmosphere. The correction is based on SWOT-independent information from the ECMWF.
- *phase_bias_cor*: Correction to the interferometric phase applied to correct for approximations in KaRIn onboard processing and systematic errors due to the variations in interferometric phase over the finite resolution of the measurement. The

values of the *interferogram* variable in the L1B_LR_INTF product have already been corrected for these biases. The uncorrected interferogram phase can be obtained by subtracting *phase_bias_cor* from the corrected *interferogram* phase (modulo 2pi radians). The value of *phase_bias_cor* is given in radians, not degrees.

4.1.2.5 Quality Measures and Flags

The following variables provide quality information about the other values in the product.

- *interferogram_qual*: Co-registered 16-bit flag that gives information on the quality of other variables in the product. Each bit of the integer represents a different flag, with 0 indicating a nominal or "good" value and 1 indicating an off-nominal or "bad" value. The definition of each bit in the flag is TBD. With all bits taken together, the 16-bit integer represents a composite flag for which a value of 0 indicates that all of the individual quality flags were nominal.
- *snr*: Signal-to-noise ratio (SNR) estimated from the data as a linear power ratio (not a decibel value). This value may be negative due to errors in estimation associated with noise subtraction.
- *num_looks*: Effective number of independent looks per sample. This value is computed analytically and is not data dependent. This value may not be an integer.

4.1.2.6 On-Board Processor Parameters

The following variables provide information on the parameters used during KaRIn on-board processing of the data.

- *doppler_centroid*: Doppler centroid value used by the KaRIn OBP (in hertz). This is a 2-D variable. One value is given per azimuth line and cross-track pixel per half swath.
- *obp_ref_surface*: Height of the reference surface used by the KaRIn OBP. The height is given relative to the reference ellipsoid whose parameters are given in the global attributes of the data product. One value is given per azimuth line per half swath.

4.1.2.7 Mitigation Products

Three mitigation fields that are passed directly from the KaRIn downlink telemetry are included in the product. The mitigation fields are two dimensional, as they are only reported for Beam 5. They include *power_miti*, the 250-m resolution range and azimuth averaged radar powers; the measured standard deviation *power_miti_std* of the original high resolution powers that went into the azimuth and range averaged data; and *info_miti* a 16 bit information flag associated with the mitigation telemetry. The meanings of these variables are TBD.

Data related to the Doppler image mitigation product is TBD.

4.1.3 Data in tvp_left and tvp_right groups

The *tvp_left and tvp_right* groups contains platform and radar system parameters as a function of time, including the spacecraft position, velocity and attitude, as well as the lever arm information of the two antennas comprising the KaRIn interferometer. See Figure 4 and its associated description for the definition of the KMSF frame.

The reason this data is given separately for each half-swath is that the phase centers of each antenna may differ by polarization (and thus half-swath). Also the temporal sampling of the *tvp_left* and *tvp_right* groups differs by the length of one transmit interval since pulses for each swath are interleaved. The differences in the times imply differences in all the parameters that vary with time.

4.1.3.1 Time

Time tags for each TVP data record are provided in the UTC and TAI time scales using the variables *time* and *time_tai*, respectively.

- *time*: Time in UTC time scale (seconds since January 1, 2000 00:00:00 UTC which is equivalent to January 1, 2000 00:00:32 TAI)
- *time_tai*: Time in TAI time scale (seconds since January 1, 2000 00:00:00 TAI, which is equivalent to December 31, 1999 23:59:28 UTC)

The variable *time* has an attribute named *tai_utc_difference*, which represents the difference between TAI and UTC (i.e., total number of leap seconds) at the time of the first measurement record in the product granule.

- *time_tai[0] = time[0] + tai_utc_difference*

The above relationship holds true for all measurement records unless an additional leap second occurs within the time span of the product granule. To account for this, the variable *time* also has an attribute named *leap_second* which provides the date at which a leap second might have occurred within the time span of the product granule. The variable *time* will exhibit a jump when a leap second occurs. If no additional leap second occurs within the time span of the product granule *time:leap_second* is set to “0000-00-00 00:00:00”.

The table below provides some examples for the values of *time*, *time_tai*, and *tai_utc_difference*. With this approach, the value of *time* will have a 1 second regression during a leap second transition, while *time_tai* will be continuous. That is, when a positive leap second is inserted, two different instances will have the same value for the variable *time*, making time non-unique by itself; the difference between *time* and *time_tai*, or the *tai_utc_difference* and *leap_second* fields, can be used to resolve this. Some examples are provided in the table below.

Table 4. Example time formats

UTC Date	TAI Date	time	time_tai	tai_utc_difference
January 1, 2000 00:00:00	January 1, 2000 00:00:32	0.0	32.0	32
December 31, 2016 23:59:59	January 1, 2017 00:00:35	536543999.0	536544035.0	36
December 31, 2016 23:59:59.5	January 1, 2017 00:00:35.5	536543999.5	536544035.5	36
December 31, 2016 23:59:60	January 1, 2017 00:00:36	536543999.0	536544036.0	37
January 1, 2017 00:00:00	January 1, 2017 00:00:37	536544000.0	536544037.0	37
January 1, 2017 12:00:00	January 1, 2017 12:00:37	536587200.0	536587237.0	37

4.1.3.2 Location, Velocity and Attitude

The position, velocity, and attitude of the KaRIn reference frame (i.e., KMSF) are given relative to the ITRF in the variables described in this section.

The attitude angles are defined as follows. Let v_{KMSF} and v_{ENU} be the same vector represented in KMSF and in the local east-north-up (ENU) frame, respectively, with the rotation matrix R giving the transformation between the two vectors representations:

$$v_{KMSF} = Rv_{ENU}$$

This rotation matrix is given by

$$R = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -\cos\, r & -\sin r \\ 0 & \sin r & -\cos r \end{bmatrix} \begin{bmatrix} \cos p & 0 & \sin p \\ 0 & 1 & 0 \\ -\sin p & 0 & \cos p \end{bmatrix} \begin{bmatrix} \sin h_p & \cos h_p & 0 \\ -\cos h_p & \sin h_p & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

where r and p represent the *roll* and *pitch* variables, and the platform heading h_p is defined as the sum of the *velocity_heading* variable h_v and the *yaw* variable h_y

$$h_p = h_v + h_y$$

with all of these angles defined modulo 360˚.

- *latitude*, *longitude*, *altitude*: Geodetic latitude, longitude, and altitude above the reference ellipsoid of the origin of the KMSF frame. The global attributes *ellipsoid_semi_major_axis* and *ellipsoid_flattening* define the reference ellipsoid.
- *roll*, *pitch*, *yaw, velocity_heading*: Attitude of the KMSF frame with respect to the local frame at the location given by *latitude* and *longitude*. The *velocity heading* is the angle with respect to true north of the nadir track direction such that if the spacecraft were flying due east, the velocity heading would be 90˚. The *yaw* is the angle of right-handed rotation of the nominal KMSF +*x* axis about the nadir direction. If the KMSF +*x* axis is aligned with the horizontal projection of the Earth-relative spacecraft velocity vector, the yaw will be zero. If the KMSF -*x* axis is aligned with the horizontal projection of the Earth-relative spacecraft velocity vector, the yaw will be 180˚. The heading of the KMSF +*x* axis relative to true north is consequently the sum of the *velocity heading* and the *yaw* (modulo 360˚). The *pitch* is defined such that a positive pitch moves the KMSF axis +*x* up. The *roll* is defined such that a positive roll moves the +*y* antenna down. Note that when the yaw is near 180˚, the sense of pitch and roll may be counterintuitive to users who are accustomed to airborne platforms since the spacecraft would be flying "tail first."
- *x*, *y*, *z*: Position vector of the KMSF origin in ECEF coordinates.
- *vx*, *vy*, *vz*: Earth-relative velocity vector of the KMSF origin in ECEF coordinates. This velocity vector describes the spacecraft motion in an Earth-fixed (not inertial) frame.

4.1.3.3 Antenna Phase Center Positions

The positions of the phase centers of the two interferometric antennas for the given swath are given at each time point in ECEF coordinates in the following variables:

- *plus_y_antenna_x*, *plus_y_antenna_y*, *plus_y_antenna_z*: Position vector of the +*y* KaRIn antenna phase center in ECEF coordinates.
- *minus_y_antenna_x*, *minus_y_antenna_y*, *minus_y_antenna_z*: Position vector of the –*y* KaRIn antenna phase center in ECEF coordinates.

4.1.3.4 Alignment Index

The index of the along-track LR (Low Rate) line corresponding to the TVP record, relative to an absolute reference, captures information about the KaRIn state and allows for alignment of granules in downstream processing to maintain the continuity of sampling across granule boundaries. This index is time-based not spatially-based. For example, the same index applies to all nine beams that were measured at the same time despite the fact that they cover different regions on the ground. One LR line also corresponds to a single line of output from the onboard processor for each half-swath.

- *record_counter*: Index (from 1 [TBC]) of the LR line corresponding to the TVP record relative to an internal KaRIn counter.

4.1.3.5 Flags

Flags in the TVP group capture information about the spacecraft and instrument state as described below. The flags should nominally be zero; nonzero values indicate off-nominal conditions.

- *sc_event_flag*: Flag that indicates spacecraft events that may affect the characteristics of the KaRIn data. An off-nominal spacecraft or KaRIn state does not necessarily imply that the data are not useful.
- *tvp_qual*: Flag that indicates the quality of the TVP data. A nonzero value indicates that the TVP data are suspect.

5 Detailed Content

The L1B_LR_INTF product adopts the NetCDF-4 file format and conventions. This is a self-documenting format that contains metadata as global attributes, dimensions, variables, and attributes for variables. Each file contains multiple NetCDF groups of data as described above. Global attributes are defined both outside and potentially inside the groups. The global attributes that are defined outside of the groups (i.e., the root NetCDF group) apply to all groups in the file, while global attributes that occur within each data group apply to only all of the data within that single group. Variable attributes only apply to the associated variable. The NetCDF command "ncdump –h product.nc" can be used to view the header of the product, which describes the content of the product.

5.1 NetCDF Variables

Variables are used to store the various measurements. Each variable is assigned a name and a particular data type. Variables can be scalar values (i.e. 0 dimension), or can have one or more dimensions. Each variable then has attributes that provide additional information about the variable. Table 5 below identifies the data types used in the L1B_LR_INTF product, and Table 6 identifies the attributes that may be assigned to each variable.

Table 5. Variable Data Types in NetCDF Product.

Data Type	Description
char	characters (ASCII)
byte	8-bit signed integer
unsigned byte	8-bit unsigned integer
short	16-bit signed integer
unsigned short	16-bit unsigned integer
int	32-bit signed integer
unsigned int	32-bit unsigned integer
long	64-bit signed integer
unsigned long	64-bit unsigned integer
float	IEEE single precision floating point (32 bits)
double	IEEE double precision floating point (64 bits)

Table 6. Common variable attributes in NetCDF file.

Attribute	Description
_FillValue	The value used to represent missing or undefined data. (Before applying add_offset and scale_factor).
add_offset	If present this value should be added to each data element after it is read. If both scale_factor and add_offset attributes are present, the data are first scaled before the offset is added.
calendar	Reference time calendar
comment	Miscellaneous information about the data or the methods to generate it.
coordinates	Coordinate variables associated with the variable
flag_meanings	Used in conjunction with flag_values. Describes the meanings of each of the elements of flag_values.
flag_values.	Used in conjunction with flag_meanings. Posssible values of the flag variable.

institution	Institution which generates the source data for the variable, if applicable.
leap_second	UTC time at which a leap second occurs within the time span of data within the file.
long_name	A descriptive variable name that indicates its content.
quality_flag	Names of variable quality flag(s) that are associated with this variable to indicate its quality.
scale_factor	If present, the data are to be multiplied by the value after they are read. If both scale_factor and add_offset attributes are present, the data are first scaled before the offset is added.
source	Data source (model, author, or instrument)
standard_name	A standard variable name that indicates its content.
tai_utc_difference	Difference between TAI and UTC reference time.
units	Unit of data after applying offset (add_offset) and scale_factor.
valid_max	Maximum theoretical value of variable before applying scale_factor and add_offset (not necessarily the same as maximum value of actual data)
valid_min	Minimum theoretical value of variable before applying scale_factor and add_offset (not necessarily the same as minimum value of actual data)

5.2 Global Attributes

Global attributes for the L1B_LR_INTF product are provided in Table 7 below.

Table 7 Global Attributes that apply to all data groups in the L1B_LR_INTF product file

Attribute	Format	Description
Conventions	string	NetCDF-4 conventions adopted in this group. This attribute should be set to CF-1.7 to indicate that the group is compliant with the Climate and Forecast NetCDF conventions.
title	string	Level 1B KaRIn Low Rate Interferogram Data Product
institution	string	Name of producing agency.
source	string	The method of production of the original data. If it was model-generated, source should name the model and its version, as specifically as could be useful. If it is observational, source should characterize it (e.g., 'Ka-band radar interferometer').
history	string	UTC time when file generated. Format is: 'YYYY-MM-DD hh:mm:ss : Creation'
platform	string	SWOT
references	string	Published or web-based references that describe the data or methods used to product it. Provides version number of software generating product.
reference_document	string	Name and version of Product Description Document to use as reference for product.
contact	string	Contact information for producer of product. (e.g., 'ops@jpl.nasa.gov').
cycle_number	short	Cycle number of the product granule.
pass_number	short	Pass number of the product granule.
equator_time	string	UTC time of the first equator crossing in product. Format is YYYY-MM-DDThh:mm:ss.ssssssZ
equator_longitude	double	Longitude of the first equator crossing in product (degrees)
time_coverage_start	string	UTC time of first measurement. Format is: YYYY-MM-DD hh:mm:ss.ssssssZ
time_coverage_end	string	UTC time of last measurement. Format is: YYYY-MM-DD hh:mm:ss.ssssssZ
geospatial_lon_min	double	Westernmost longitude (deg) of granule bounding box
geospatial_lon_max	double	Easternmost longitude (deg) of granule bounding box
geospatial_lat_min	double	Southernmost latitude (deg) of granule bounding box
geospatial_lat_max	double	Northernmost latitude (deg) of granule bounding box

left_first_longitude	double	Nominal swath corner longitude for the first range line and left edge of the swath (degrees_east)
left_first_latitude	double	Nominal swath corner latitude for the first range line and left edge of the swath (degrees_north)
left_last_longitude	double	Nominal swath corner longitude for the last range line and left edge of the swath (degrees_east)
left_last_latitude	double	Nominal swath corner latitude for the last range line and left edge of the swath (degrees_north)
right_first_longitude	double	Nominal swath corner longitude for the first range line and right edge of the swath (degrees_east)
right_first_latitude	double	Nominal swath corner latitude for the first range line and right edge of the swath (degrees_north)
right_last_longitude	double	Nominal swath corner longitude for the last range line and right edge of the swath (degrees_east)
right_last_latitude	double	Nominal swath corner latitude for the last range line and right edge of the swath (degrees_north)
wavelength	double	Wavelength (m) of the transmitted signal, which is determined based on the transmitter center frequency of the transmit chirp.
transmit_antenna	string	Flag indicating which of the KaRIn antennas (plus_y or minus_y) is transmitting.
antenna_to_kmsf_roll_hpol	double	The antenna frame to KMSF frame roll bias angle in degrees for H-pol swath. A positive sign indicates TBD.
antenna_to_kmsf_pitch_hpol	double	The antenna frame to KMSF frame pitch angle in degrees for H-pol swath. A positive sign indicates TBD.
antenna_to_kmsf_yaw_hpol	double	The antenna frame to KMSF frame yaw angle in degrees for H-pol swath. A positive sign indicates TBD.
antenna_to_kmsf_roll_vpol	double	The antenna frame to KMSF frame roll bias angle in degrees for V-pol swath. A positive sign indicates TBD.
antenna_to_kmsf_pitch_vpol	double	The antenna frame to KMSF frame pitch angle in degrees for V-pol swath. A positive sign indicates TBD.
antenna_to_kmsf_yaw_vpol	double	The antenna frame to KMSF frame yaw angle in degrees for V-pol swath. A positive sign indicates TBD.
xref_input_orbit_ephemeris_file	string	Name of input orbit ephemeris file.
xref_input_attitude_file	string	Name of input reconstructed attitude file.
xref_input_satcom_file	string	Name of input satellite center-of-mass file.
xref_input_gcrfitrf_file	string	Name of input file with conversion between Geocentric Celestial Reference Frame (inertial) and International Terrestrial Reference Frame
xref_input_l0b_lr_frame_file	string	Name of input Level 0B frame file.
xref_input_static_karin_cal_file	string	Name of input static KaRIn calibration file.
xref_input_int_kcal_dyn_file	string	Name of input dynamic KaRIn calibration file.
xref_input_leapsec_file	string	Name of input leap seconds file.
xref_input_histo_oef_file	string	Name of input satellite events file.
xref_input_static_geophys_files	string	List of static geophysical parameter files
xref_input_dynamic_geophys_files	string	List of dynamic geophysical parameter files (TBR: to be split into specific input types)
xref_l1b_lr_intf_config_parameters_file	string	Name of input processor configuration parameters file.
ellipsoid_semi_major_axis	double	Semi-major axis of reference ellipsoid in meters.
ellipsoid_flattening	double	Flattening of reference ellipsoid

5.3 Group Names, Attributes, and Dimensions

As described in Table 2 the L1B_LR_INTF product file contains four NetCDF data groups called the *left, right, tvp_left,* and *tvp_right* groups.

Each group has a 'description' attribute that elaborates on what the data in the group represents.

Each NetCDF group uses the dimensions attributes to identify the physical dimensions of variables within that single group. The L1B_LR_INTF product uses the dimensions shown in Table 12.

Note that the length *num_lines* for the *left* and *right* groups is always the same as the length *num_tvps* for the *tvp_left and tvp_*right groups since there is a one-to-one mapping between azimuth lines and TVP records in the L1B_LR_INTF product.

Table 8. Attributes of the *left* group of the L1B_LR_INTF product.

Attribute	Format	Description
description	string	KaRIn bias-corrected interferogram and associated information for the half swath to the left (when facing the velocity direction) of the nadir track.

Table 9. Attributes of the *right* group of the L1B_LR_INTF product.

Attribute	Format	Description
description	string	KaRIn bias-corrected interferogram and associated information for the half swath to the right (when facing the velocity direction) of the nadir track.

Table 10. Attributes of the *tvp_left* group of the L1B_LR_INTF product.

Attribute	Format	Description
description	string	Time varying parameters group including spacecraft attitude, position, velocity, and antenna position information used for the left-hand swath.

Table 11. Attributes of the *tvp_right* group of the L1B_LR_INTF product.

Attribute	Format	Description
description	string	Time varying parameters group including spacecraft attitude, position, velocity, and antenna position information used for the right-hand swath.

Table 12. Dimensions of variables in NetCDF file.

Name	Description
num_tvps	The number of records in each TVP group. There is a one-to-one correspondence with the number of azimuth lines in the left and right groups.
num_beams	The number of Doppler beams formed by the KaRIn on-board processor. This length is always 9.
num_lines	Number of along-track or azimuth lines in each of the left and right half swaths.
num_pixels	Number of cross-track pixels in each of the left and right half swaths. The index increases outward from nadir.
num_coord	Coordinates in 3-D space. X,Y, Z in that order.
complex_depth	Size 2 dimension used to represent a complex number as two floats. Real and imaginary in that order.

5.4 Detailed NetCDF format description

This section provides a detailed listing of each of the variables within each of the groups in the L1B_LR_INTF NetCDF file.

The variables of the *left* and *right* groups have identical definitions and are both described by Table 13.

Table 13. Variables in each of the *left* and *right* groups.

Group *left* and Group *right* Variables		
double reference_location(num_beams, num_lines, num_pixels, num_coord)		
	_FillValue	9.969209968386869e+36
	long_name	reference location
	units	m
	valid_min	-10000000.0
	valid_max	10000000.0
	comment	Location on the Earth surface, defined by a reference surface, to which the measured phase is referred. The location is given in ECEF coordinates with the X, Y, and Z components given in the coord array dimension.
int reference_latitude(num_beams, num_lines, num_pixels)		
	_FillValue	2147483647
	long_name	reference latitude (positive N, negative S)
	standard_name	latitude
	units	degrees_north
	scale_factor	0.000001
	valid_min	-80000000
	valid_max	80000000
	comment	Latitude of the location on the Earth surface, defined by a reference surface, to which the measured phase is referred. Positive latitude is North latitude, negative latitude is South latitude.
int reference_longitude(num_beams, num_lines, num_pixels)		
	_FillValue	2147483647
	long_name	reference longitude
	standard_name	longitude
	units	degrees_east
	scale_factor	0.000001
	valid_min	0
	valid_max	359999999
	comment	Longitude of the location on the Earth surface, defined by a reference surface, to which the measured phase is referred. East longitude relative to Greenwich meridian.
float interferogram(num_beams, num_lines, num_pixels, complex_depth)		
	_FillValue	9.96921e+36
	long_name	complex interferogram
	units	1
	valid_min	-1.0
	valid_max	1.0
	coordinates	reference_longitude reference_latitude
	comment	Complex interferogram. The real and imaginary parts are in the complex_depth array dimension. The magnitude of the interferogram represents the total interferometric correlation.
float phase_uncert(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	phase 1-sigma uncertainty
	units	rad

	valid_min	0.0
	valid_max	100.0
	coordinates	reference_longitude reference_latitude
	comment	1-sigma uncertainty computed analytically using observed correlation and effective number of looks. Two-sided error bars (phase-phase_uncert,phase+phase_uncert) include approximately 68% of probability distribution.
float sig0(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	sigma0
	units	1
	valid_min	-1000
	valid_max	10000000
	coordinates	reference_longitude reference_latitude
	comment	Normalized radar cross section in linear units (not decibels).
float sig0_uncert(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	sigma0 1-sigma uncertainty
	units	1
	valid_min	0.0
	valid_max	100.0
	coordinates	reference_longitude reference_latitude
	comment	1-sigma uncertainty computed analytically using estimated signal to noise ratio and effective number of looks. Two-sided error bars (sig0-sig0_uncert,sig0+sig_uncert) include 68% of probability distribution.
float volumetric_correlation(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	volumetric correlation
	units	1
	valid_min	0.0
	valid_max	2.0
	coordinates	reference_longitude reference_latitude
	comment	Volumetric correlation.
float volumetric_correlation_uncert(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	volumetric correlation standard deviation
	units	1
	valid_min	0.0
	valid_max	100.0
	coordinates	reference_longitude reference_latitude
	comment	1-sigma uncertainty computed analytically using observed correlation and effective number of looks. Two-sided error bars (volumetric_correlation-volumetric_correlation_uncert, volumetric_correlation+volumetric_correlation_uncert) include 68% of probability distribution.
float angular_correlation(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	angular correlation
	units	1
	valid_min	0.0
	valid_max	2.0
	coordinates	reference_longitude reference_latitude
	comment	Angular correlation.
float geometric_correlation(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36

	long_name	geometric correlation
	units	1
	valid_min	0.0
	valid_max	2.0
	coordinates	reference_longitude reference_latitude
	comment	Geometric correlation.
float noise_correlation(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	noise correlation
	units	1
	valid_min	0.0
	valid_max	2.0
	coordinates	reference_longitude reference_latitude
	comment	Noise correlation.
float x_factor_plus_y(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	radiometric calibration X factor for plus_y channel
	units	1
	valid_min	0.0
	valid_max	1e+20
	coordinates	reference_longitude reference_latitude
	comment	Radiometric calibration X factor as a linear power ratio for the plus_y channel.
float x_factor_minus_y(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	radiometric calibration X factor for minus_y channel
	units	1
	valid_min	0.0
	valid_max	1e+20
	coordinates	reference_longitude reference_latitude
	comment	Radiometric calibration X factor as a linear power ratio for the minus_y channel.
float uncalibrated_power_plus_y(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	uncalibrated power for plus_y channel
	units	1
	valid_min	0.0
	valid_max	1e+20
	coordinates	reference_longitude reference_latitude
	comment	Uncalibrated power for plus_y channel in linear units.
float uncalibrated_power_minus_y(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	uncalibrated power for minus_y channel
	units	1
	valid_min	0.0
	valid_max	1e+20
	coordinates	reference_longitude reference_latitude
	comment	Uncalibrated power for minus_y channel in linear units.
float noise_power_plus_y(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	noise power for plus_y channel
	units	1
	valid_min	0.0
	valid_max	1e+20
	coordinates	reference_longitude reference_latitude

	comment	Noise power for plus_y channel in linear units.
float noise_power_minus_y(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	noise power for minus_y channel
	units	1
	valid_min	0.0
	valid_max	1e+20
	coordinates	reference_longitude reference_latitude
	comment	noise power for minus y channel in linear unis.
float model_dry_tropo_cor(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	dry troposphere vertical correction
	source	European Centre for Medium-Range Weather Forecasts
	units	m
	valid_min	-3
	valid_max	-1.5
	coordinates	reference_longitude reference_latitude
	comment	Equivalent vertical correction due to dry troposphere delay. The reported pixel height, latitude and longitude are computed after adding negative media corrections to uncorrected range along slant-range paths, accounting for the differential delay between the two KaRIn antennas. The equivalent vertical correction is computed by applying obliquity factors to the slant-path correction. Adding the reported correction to the reported pixel height results in the uncorrected pixel height.
float model_wet_tropo_cor(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	wet troposphere vertical correction
	source	European Centre for Medium-Range Weather Forecasts
	units	m
	valid_min	-1
	valid_max	0
	coordinates	reference_longitude reference_latitude
	comment	Equivalent vertical correction due to wet troposphere delay. The reported pixel height, latitude and longitude are computed after adding negative media corrections to uncorrected range along slant-range paths, accounting for the differential delay between the two KaRIn antennas. The equivalent vertical correction is computed by applying obliquity factors to the slant-path correction. Adding the reported correction to the reported pixel height results in the uncorrected pixel height.
float iono_cor_gim_ka(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	ionosphere vertical correction
	source	NASA/JPL Global Ionosphere Map
	units	m
	valid_min	-0.5
	valid_max	0
	coordinates	reference_longitude reference_latitude
	comment	Equivalent vertical correction due to ionosphere delay. The reported pixel height, latitude and longitude are computed after adding negative media corrections to uncorrected range along slant-range paths, accounting for the differential delay between the two KaRIn antennas. The equivalent vertical correction is computed by applying obliquity factors to the slant-path correction. Adding the reported correction to the reported pixel height results in the uncorrected pixel height.
float phase_bias_cor(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	total phase bias correction

	units	rad
	valid_min	-3.141592653589793
	valid_max	3.141592653589793
	coordinates	reference_longitude reference_latitude
	comment	Total phase bias correction.
unsigned short interferogram_qual(num_beams, num_lines, num_pixels)		
	_FillValue	65535
	long_name	quality flag
	standard_name	status_flag
	flag_masks	[1 2]
	flag_meanings	not_useable missing_doppler_fit
	valid_min	0
	valid_max	3
	coordinates	reference_longitude reference_latitude
	comment	Quality flag.
float snr(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	signal to noise ratio
	units	1
	valid_min	-999999.0
	valid_max	999999.0
	coordinates	reference_longitude reference_latitude
	comment	Signal to noise ratio as a linear power ratio.
float num_looks(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	number of looks
	units	1
	valid_min	0.0
	valid_max	5000.0
	coordinates	reference_longitude reference_latitude
	comment	Effective number of independent looks.
float sig0_cor_atmos_model(num_beams, num_lines, num_pixels)		
	_FillValue	9.96921e+36
	long_name	atmospheric attenuation
	units	1
	valid_min	1.0
	valid_max	10.0
	coordinates	reference_longitude reference_latitude
	comment	Atmospheric correction to sigma0 from weather model data as a linear power multiplier (not decibels).
float doppler_centroid(num_lines)		
	_FillValue	9.96921e+36
	long_name	On-board processor Doppler value
	units	1/s
	valid_min	-1000000
	valid_max	1000000
	comment	On-board processor Doppler value.
float obp_ref_surface(num_lines)		
	_FillValue	9.96921e+36
	long_name	On-board processor reference surface height
	units	m
	valid_min	-1500
	valid_max	15000

	comment	On-board processor reference surface height relative to the reference ellipsoid.
int power_miti(num_lines, num_pixels)		
	_FillValue	2147483647
	long_name	mitigation power
	units	1
	valid_min	0
	valid_max	65534
	comment	Mitigation power; TBD.
int power_miti_std(num_lines, num_pixels)		
	_FillValue	2147483647
	long_name	mitigation power standard deviation
	units	1
	valid_min	0
	valid_max	65534
	comment	Mitigation power standard deviation; TBD.
unsigned short info_miti(num_lines, num_pixels)		
	_FillValue	65535
	long_name	mitigation power flag
	standard_name	status_flag
	flag_meanings	...
	flag_values	. . .
	valid_min	0
	valid_max	65534
	comment	Mitigation power flag; TBD

The variables of the *tvp_left* and *tvp_right* groups have identical definitions and are both described by Table 14.

Table 14. Variables of the *tvp_left* and *tvp_right* groups.

Group *tvp_left* and Group *tvp_right* Variables		
double time(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	time in UTC
	standard_name	time
	calendar	gregorian
	tai_utc_difference	[Value of TAI-UTC at time of first record]
	leap_second	YYYY-MM-DD hh:mm:ss
	units	seconds since 2000-01-01 00:00:00.000
	comment	Time of measurement in seconds in the UTC time scale since 1 Jan 2000 00:00:00 UTC. [tai_utc_difference] is the difference between TAI and UTC reference time (seconds) for the first measurement of the data set. If a leap second occurs within the data set, the attribute leap_second is set to the UTC time at which the leap second occurs.
double time_tai(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	time in TAI
	standard_name	time
	calendar	gregorian
	units	seconds since 2000-01-01 00:00:00.000

	comment	Time of measurement in seconds in the TAI time scale since 1 Jan 2000 00:00:00 TAI. This time scale contains no leap seconds. The difference (in seconds) with time in UTC is given by the attribute [time:tai_utc_difference].
double latitude(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	latitude (positive N, negative S) of the spacecraft
	standard_name	latitude
	units	degrees_north
	valid_min	-80.0
	valid_max	80.0
	comment	Geodetic latitude of the KMSF origin with respect to the reference ellipsoid.
double longitude(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	longitude (degrees East) of the spacecraft
	standard_name	longitude
	units	degrees_east
	valid_min	0
	valid_max	360.0
	comment	Longitude of the KMSF origin, with positive values indicating longitudes east of the Greenwich meridian.
double altitude(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	altitude of the spacecraft
	units	m
	valid_min	0.0
	valid_max	1000000.0
	coordinates	longitude latitude
	comment	Altitude above the reference ellipsoid of the KMSF origin.
double roll(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	roll of the spacecraft
	units	degrees
	valid_min	-180
	valid_max	180
	coordinates	longitude latitude
	comment	KMSF attitude roll angle; positive values move the +y antenna down.
double pitch(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	pitch of the spacecraft
	units	degrees
	valid_min	-180
	valid_max	180
	coordinates	longitude latitude
	comment	KMSF attitude pitch angle; positive values move the KMSF +x axis up.
double yaw(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	yaw of the spacecraft
	units	degrees
	valid_min	-180
	valid_max	180
	coordinates	longitude latitude
	comment	KMSF attitude yaw angle relative to the nadir track. The yaw angle is a right-handed rotation about the nadir (downward) direction. A yaw value of 0 deg indicates that the

		KMSF +x axis is aligned with the horizontal component of the Earth-relative velocity vector. A yaw value of 180 deg indicates that the spacecraft is in a yaw-flipped state, with the KMSF -x axis aligned with the horizontal component of the Earth-relative velocity vector.
double velocity_heading(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	heading of the spacecraft Earth-relative velocity vector
	units	degrees
	valid_min	0
	valid_max	360
	coordinates	longitude latitude
	comment	Angle with respect to true north of the horizontal component of the spacecraft Earth-relative velocity vector. A value of 90 deg indicates that the spacecraft velocity vector pointed due east. Values between 0 and 90 deg indicate that the velocity vector has a northward component, and values between 90 and 180 deg indicate that the velocity vector has a southward component.
double x(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	x coordinate of the spacecraft in the ECEF frame
	units	m
	valid_min	-10000000.0
	valid_max	10000000.0
	comment	x coordinate of the KMSF origin in the ECEF frame.
double y(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	y coordinate of the spacecraft in the ECEF frame
	units	m
	valid_min	-10000000.0
	valid_max	10000000.0
	comment	y coordinate of the KMSF origin in the ECEF frame.
double z(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	z coordinate of the spacecraft in the ECEF frame
	units	m
	valid_min	-10000000.0
	valid_max	10000000.0
	comment	z coordinate of the KMSF origin in the ECEF frame.
double vx(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	x component of the spacecraft velocity in the ECEF frame
	units	m/s
	valid_min	-10000.0
	valid_max	10000.0
	coordinates	longitude latitude
	comment	KMSF velocity component in x direction in the ECEF frame.
double vy(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	y component of the spacecraft velocity in the ECEF frame
	units	m/s
	valid_min	-10000.0
	valid_max	10000.0
	coordinates	longitude latitude
	comment	KMSF velocity component in y direction in the ECEF frame.

double vz(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	z component of the spacecraft velocity in the ECEF frame
	units	m/s
	valid_min	-10000.0
	valid_max	10000.0
	coordinates	longitude latitude
	comment	KMSF velocity component in z direction in the ECEF frame.
double plus_y_antenna_x(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	x coordinate of the plus_y antenna phase center in the ECEF frame
	units	m
	valid_min	-10000000.0
	valid_max	10000000.0
	comment	x coordinate of the plus_y antenna phase center in the ECEF frame.
double plus_y_antenna_y(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	y coordinate of the plus_y antenna phase center in the ECEF frame
	units	m
	valid_min	-10000000.0
	valid_max	10000000.0
	comment	y coordinate of the plus_y antenna phase center in the ECEF frame.
double plus_y_antenna_z(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	z coordinate of the plus_y antenna phase center in the ECEF frame
	units	m
	valid_min	-10000000.0
	valid_max	10000000.0
	comment	z coordinate of the plus_y antenna phase center in the ECEF frame.
double minus_y_antenna_x(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	x coordinate of the minus_y antenna phase center in the ECEF frame
	units	m
	valid_min	-10000000.0
	valid_max	10000000.0
	comment	x coordinate of the minus_y antenna phase center in the ECEF frame.
double minus_y_antenna_y(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	y coordinate of the minus_y antenna phase center in the ECEF frame
	units	m
	valid_min	-10000000.0
	valid_max	10000000.0
	comment	y coordinate of the minus_y antenna phase center in the ECEF frame.
double minus_y_antenna_z(num_tvps)		
	_FillValue	9.969209968386869e+36
	long_name	z coordinate of the minus_y antenna phase center in the ECEF frame
	units	m
	valid_min	-10000000.0
	valid_max	10000000.0
	comment	z coordinate of the minus_y antenna phase center in the ECEF frame.
int record_counter(num_tvps)		
	_FillValue	2147483647
	long_name	record counter

	units	1
	valid_min	1
	valid_max	999999999
	coordinates	longitude latitude
	comment	Index of the TVP record used to align data samples across granules.
byte sc_event_flag(num_tvps)		
	_FillValue	127
	standard_name	status_flag
	flag_meanings	nominal not_nominal
	flag_values	0 1
	valid_min	0
	valid_max	1
	coordinates	longitude latitude
	comment	Spacecraft event flag
byte tvp_qual(num_tvps)		
	_FillValue	127
	standard_name	status_flag
	flag_meanings	good bad
	flag_values	0 1
	valid_min	0
	valid_max	1
	coordinates	longitude latitude
	comment	Quality flag for TVP data

6 References

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Appendix A. **Acronyms**

ATBD	Algorithm Theoretical Basis Document
CNES	Centre National d'Études Spatiales
ECEF	Earth-Centered, Earth-Fixed (frame)
ECMWF	European Centre for Medium-Range Weather Forecasts
GIM	Global Ionosphere Maps
H	Horizontally polarized signal
HPA	High Power Amplifier
HR	High Rate
ITRF	International Terrestrial Reference Frame
JPL	Jet Propulsion Laboratory
KaRIn	Ka-band Radar Interferometer (instrument)
KMSF	KaRIn Metering Structure Frame
LR	Low Rate
NASA	National Aeronautics and Space Administration
NESZ	Noise-Equivalent Sigma Zero
NRCS	Normalized Radar Cross Section
OBP	On-Board Processor
SAR	Synthetic Aperture Radar
SNR	Signal-to-Noise Ratio
SWOT	Surface Water and Ocean Topography (mission)
TAI	Temps Atomique International / International Atomic Time
TBC	To Be Confirmed
TBD	To Be Determined

TVP	Time Varying Parameters
UTC	Coordinated Universal Time
V	Vertically polarized signal
X factor	Radiometric normalization and calibration factor (not an acronym)